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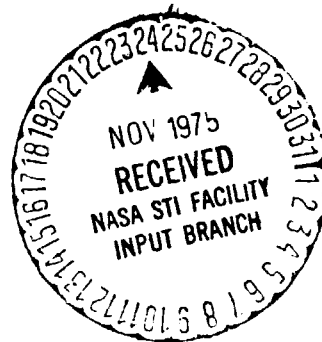
INVESTIGATION OF MODELS FOR LARGE-SCALE  
METEOROLOGICAL PREDICTION EXPERIMENTS

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# INVESTIGATION OF MODELS FOR LARGE-SCALE METEOROLOGICAL PREDICTION EXPERIMENTS

## Introduction

The general objective of the project, which was begun at The City College on 1 October 1973, has been to study the feasibility of extended and long-range weather prediction by means of global atmospheric models. The project, in pursuit of this objective, has engaged in a close collaboration with the Goddard Institute for Space Studies (GISS), and has conducted a number of computer experiments at GISS with the GISS global general circulation model. Project staff members provide technical support and consulting services to GISS in the areas of meteorological analysis and interpretation of experimental results, and are provided by GISS with excellent computing services for their own prediction experiments. Thus the project represents a cooperative effort between the City College and GISS.

During the past year the project staff has consisted of the principal investigator and two graduate students, Robert Atlas ( a candidate for the Ph. D., at New York University) and Eugene Kuo (a candidate for the M.S. degree at The City College), plus a part-time secretary. Drafting services are provided by the CUNY Institute of Marine and Atmospheric Sciences at The City College.

## Atmospheric Response to Sea-Surface

### Temperature Anomalies

The project has conducted two sets of experiments with the GISS 9-level global general circulation model (Somerville, et al., 1974) to test the impact of temporal sea-surface temperature (SST) variations on the predictive output of the model.

In the first of these experiments the model was used to generate a two-week prediction starting with global initial data for 20 December 1972. Two parallel forecasts were computed. In one run, the surface fluxes of heat and water vapor over the oceans were calculated using the climatological monthly mean SST field for January. In a second run, the climatological SST field was replaced by the observed SST field for 20 December 1972. The results of this extended-range forecast experiment have been described in a paper (Spar and Atlas, 1975) published in the October 1975 issue of the Journal of Applied Meteorology from which the following abstract is quoted.

A two-week prediction experiment was performed with the GISS atmospheric model on a global data set beginning 20 December 1972 to test the sensitivity of the model to sea-surface temperature (SST) variations. Use of observed SST's in place of climatological monthly mean sea temperature for surface flux calculations in the model was found to have a marked local effect on predicted precipitation over the ocean, with enhanced convection over warm SST anomalies. However, use

of observed SST's did not lead to any detectable general improvement in forecast skill. The influence of the SST anomalies on daily predicted fields of pressure and geopotential was small up to about one week compared with the growth of prediction error, and no greater over a two-week period than that resulting from random errors in the initial meteorological state. The 14-day average fields of sea-level pressure and 500-mb height predicted by the model were similarly insensitive to the SST anomalies.

The two-week forecast experiment clearly demonstrated that the influence of SST anomalies grows so slowly that it is overwhelmed by the decay of predictability before it can significantly affect the model atmosphere. In a second experiment, therefore, the model was run for a period of one month to allow the influence of the SST anomalies sufficient time to develop. The output of this experiment was analyzed mainly in terms of monthly mean forecast and observed states, in recognition of the rapid decay of daily predictability. Furthermore, the observed SST field was altered daily during the 30-day forecast run. Daily updating of the SST field was intended to simulate the operation of an idealized coupled air-sea model in which the oceanic part of the forecast might provide a perfect prediction of the sea temperatures as input to the atmospheric computation.

The monthly SST update experiment was carried out for January 1974, starting with global data for 00GMT on the first day of the month. SST data obtained from the National Environmental Satellite Service of NOAA, through the National Meteorological Center, and based largely on satellite scanning radiometer measurements, together with data from the

Navy Fleet Numerical Weather Central, were used to derive an SST field for each day of the month. Two parallel forecasts were then computed for the month, one based on a fixed mean January climatological SST field and the other on the daily updated SST values.

From an analysis of sea-level pressure, 500-mb height, and 850-mb temperature fields, it was found that the use of daily updated SST information produced no detectable beneficial impact on either daily or monthly mean forecasts compared with the forecasts computed from the climatological SST field. Thus, the monthly forecast experiment confirmed the result of the two-week experiment, and again indicated that substantial improvements in the predictive skill of atmospheric models will be necessary before any beneficial impact of updated sea temperatures on the large-scale pressure and wind fields can be demonstrated in extended and long-range forecasts.

(A report on the monthly experiment is included in a paper, "Monthly Mean Forecast Experiments with the GISS Model", which is now being prepared for publication. A preliminary report on the experiment by Spar, Atlas, and Kuo, titled "A 30-day Forecast Experiment with the GISS Model and Updated Sea-Surface Temperatures", has already been distributed.)

## Monthly Mean Forecast Experiments with the GISS Model

The GISS 9-level global model has been used in a long-range forecasting experiment to determine if it exhibits skill in predicting the monthly mean state of the atmosphere. Starting with global initial data for 00 GMT on the first day of each month, a global 30-day forecast was computed for January of 1973, 1974, and 1975. The forecasts were read out at 12-hourly intervals (00 and 12 GMT), and a monthly mean forecast was computed for each January. In these forecasts, the fixed climatological mean January SST field was used for the calculation of surface fluxes over the oceans.

The forecasts were evaluated in terms of global and hemispheric energetics, zonally-averaged meridional and vertical profiles, forecast error statistics, and monthly mean synoptic fields. Among the outputs analyzed from the 9-level global forecasts were fields of geopotential, temperature, wind, zonal and eddy energy, and sea-level pressure.

From the three January forecasts made with the GISS model we find that, while the model is capable of simulating realistically the general structure and circulation of the mean troposphere, it does not yet account satisfactorily for the observed interannual variations in the monthly mean energetics and circulation of the atmosphere. Thus, it cannot be concluded that the model correctly simulates the dependence of each monthly mean state of the atmosphere on the initial conditions at the beginning of the month. (Nor indeed has it been possible to demonstrate that the observed monthly mean

state is in fact determined by the initial conditions as defined by the global analysis.)

As a long-range forecasting system, the GISS model exhibits no skill in predicting the monthly mean sea-level pressure field. However, the model does show some modest skill in predicting monthly mean temperatures at the 850-mb level, and appears to have considerable skill at the 500-mb level. The monthly mean 500-mb geopotential height fields forecast by the model are consistently superior to both persistence and climatology when evaluated in terms of either root-mean-square (rms) errors or S-1 (horizontal gradient) skill scores. The model's performance is particularly outstanding in the prediction of the 500-mb height fields over the United States, where the mean rms error for the three Januarys is only 55 meters (compared with 113 meters for climatology and 112 meters for persistence) and the "percentage skill" in forecasting horizontal gradients is 78% (compared with 54% for climatology and 28% for persistence).

Although the results above are based on only three forecasts, and are therefore hardly conclusive, the positive indications at the 500-mb level are highly encouraging, and warrant continued testing of the model for monthly prediction. On the other hand, the need for further model improvement is clearly suggested by the negative results of the prediction experiments. (The monthly prediction experiments are described in a paper by Spar, Kuo, and Atlas, titled "Monthly Mean Forecasts with the GISS Model", now being completed for publication.)

The Prediction of Sea-Surface Temperature  
Variations with an Advective Mixed-Layer Ocean Model  
(Robert M. Atlas)

Despite the negative results thus far of the experiments in extended and monthly atmospheric prediction with variable SST fields, it is nevertheless obviously desirable to develop the capability of forecasting the temperature of the ocean surface. Whether these SST forecasts are used for their own sake (e. g., in such marine applications as the fishing industry), or as part of a coupled sea-air model for weather prediction, ocean prediction is both a scientific challenge and a practical objective.

It is well known that the upper layers of the oceans undergo substantial temperature variations, and that these variations are primarily brought about by solar and long wave radiation, heat exchange with the atmosphere, and heat transfer within the ocean itself. Despite numerous studies of oceanic heat transfer, there are still conflicting opinions regarding the role of temperature advection and the need for its inclusion in numerical models of the upper ocean.

In recent years several one-dimensional mixed-layer ocean models (e.g., Kraus and Turner, 1967, Denman, 1973) have been developed for the purpose of short and medium range SST prediction. These models, which are primarily based on the conservation equations for heat and mechanical energy, provide reasonable predictions for the changes in mixed-layer

depth and sea-surface temperature. However, because of the assumption of a horizontally homogeneous ocean and the one-dimensional nature of the models, they neglect or do not adequately take account of important dynamical effects such as advection of heat by horizontal ocean currents and upwelling and downwelling.

The one dimensional mixed-layer ocean model developed by Denman (1973) has been adapted for global use by Miller (1973). This "GISS Ocean Model" has a horizontal grid spacing of  $4^{\circ}$  in latitude and  $5^{\circ}$  in longitude. Despite the fact that this is a global grid, the one-dimensional nature of the Denman model was not changed in the GISS version, and the predictions at each grid point are carried out independently.

In the Denman model, the ocean is assumed to be an incompressible, horizontally homogeneous, stably stratified fluid. To account for the horizontal advection of heat at each gridpoint, we have eliminated the assumption of a horizontally homogeneous temperature field, thus allowing horizontal temperature gradients. In addition, a mean and anomalous wind driven current field has been superimposed on the grid. By taking this approach, we still allow the Denman model to account for the effects of solar and infrared radiation, sensible and latent heat exchange with the atmosphere, and mixed-layer depth changes at each point, while the superimposed current field serves to couple the gridpoints through the advection of heat and mass.

A series of experiments has been carried out with this "Advective Mixed-Layer Ocean Model" in order to determine (1) if advective effects are significant within the model and if it results in an improvement in the accuracy of the predictions, (2) for what regions (and times) advective effects are most important, (3) the relative importance of advection and mixed-layer deepening in predicting sea surface temperature changes, and (4) the effect of anomalous wind-generated ocean currents on the sea surface temperature field. Although the evaluation of these experiments is not yet complete, it is possible to present some of the results at this time.

In the first phase of experimentation, the model's ability to predict climatological SST variations was evaluated. Two 3-month prediction experiments (one in the cooling season and one in the heating season) were conducted. Tables I and II illustrate the results of the cooling season experiment, in which January mean sea surface temperatures served as the initial condition and mean fluxes were used to drive the model. SST predictions were evaluated at the end of thirty, sixty, and ninety days for three different versions of the mixed-layer model. Model (A) refers to the original version of the GISS Ocean Model in which no advection is included. Model (B) is the same as (A) except that in this case advection by mean ocean currents is included. Model (C) is the same as (B) except that in this case the mixed-layer depth is held constant with time and therefore no deepening is allowed to occur.

**Table I.** Average Absolute Error ( $^{\circ}\text{C}$ ) in the Prediction of Climatological Sea Surface Temperatures from January Initial Conditions.

**A.) North Atlantic**

Model		30	60	90	DAYS
					(Non-advective)
	A	.49	.72	1.13	(Advective-variable depth)
	B	.26	.39	.54	(Advective-constant depth)
	C	.37	.75	.99	(Persistence)
	P	.68	.60	.62	

**B.) North Pacific**

Model		30	60	90	DAYS
					(Non-advective)
	A	.48	.72	1.12	(Advective-variable depth)
	B	.29	.42	.55	(Advective-constant depth)
	C	.36	.67	.98	(Persistence)
	P	.72	.58	.65	

**Table II.** Percentage of Gridpoints Improved When Advective is Included (January experiment. Model B.)

	30	60	90	DAYS
North Atlantic	68	67	71	
North Pacific	62	61	65	

This model was included to determine the importance of mixed-layer deepening in the Advective Model, since earlier advective models of the upper ocean (Adem, 1970; Clark, 1972) did not account for mixed-layer depth changes. The fourth result in Table I, denoted by (P), is for a persistence forecast, and is included for comparison, to determine if any of the three forecasts possess skill over persistence.

Tables III and IV present the results for the heating season experiment in which June climatological sea surface temperatures were used as initial conditions. The summer mean current field differs from the winter mean current field mainly in that the currents are considerably more meridional in the North Pacific and only slightly weaker. Also the mixed-layer depths were much smaller in the summer experiment, and therefore the upper level currents averaged over the entire mixed-layer were stronger. These two properties combined to yield a larger advective effect in the summer experiment.

From the tables, it can be seen that the inclusion of advection resulted in an improvement in the prediction at more than sixty per cent of the gridpoints, and that a significant decrease in average absolute error occurred in each case for both the North Atlantic and North Pacific. It is also interesting to note that only the advective version (B) consistently maintains predictive skill over persistence.

The results of these two experiments indicate that the effect of advection is quite significant and therefore should be included in numerical models of the upper ocean. The effect of mixed-layer depth changes is also significant (as evidenced by a comparison of the results from versions (B) and (C)), and this effect must also be included.

After the completion of the above experiments, a series of sensitivity tests was conducted in order to evaluate the role of anomalous wind generated ocean currents. The climatological predictions of the first phase were set up as control runs upon which, hypothetical anomalous winds were superimposed. Tests were conducted for which the winds were increased, decreased, and reversed, and for which major pressure systems (hence winds) were shifted either zonally or meridionally. Although the analysis of this experiment is not yet complete, the results indicate that the model is sensitive to these anomalous winds, and that anomalous advection does contribute to the generation, maintenance, movement, and dissipation of large scale SST anomalies.

A third experiment is currently underway to evaluate the predictive skill of the Advective Mixed-Layer Model using synoptic data. Preliminary results from this experiment indicate that the accuracy of the predictions is somewhat worse for synoptic than for climatological data, but that the advective effect is still important.

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